

Leica Geosystems Single to Multi Frequency GNSS Signal Processing Solutions for Engineering Infrastructures Monitoring Applications

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Abstract

Nothing is static. Buildings and dams settle, bridges flex and vibrate, rock masses shift, mud slides, glaciers flow, volcanoes erupt. Whether by human activity such as mining or construction or by the natural processes of erosion, the world in which we live is continually changing. Management of this change is essential for social and economic advancement. Failure of a bridge can isolate communities, restrict commerce and cause loss of life.

A landslide can close a mine and cause huge financial and human loss and even impact world mineral prices. Economies, even our daily lives, are dependent upon the health of bridges, dams, tunnels, elevated road systems, retaining walls, mines, and high-rise buildings. Engineers, geologists and other professionals are trusted to prevent such disasters.

Engineering companies and contractors are facing challenges never before experienced. They are being charged with – and being held liable for – the health of the structures they create and maintain. In order to surmount these challenges, engineers need to be able to detect structural movements to millimeter level accuracy and track these movements in real time in all atmospheric conditions.

Accurate and timely information on the actual status of the structure is highly valuable to engineers, enabling them to compare the real-world behavior of the structure against the design and theoretical models. When armed with such data, engineers can effectively and cost efficiently measure and maintain the health of these vital infrastructures.

Owing to the advantages of high accuracy, all-weather conditions and no requirements of inter-visibility between measuring points, GNSS, the acronym standing for Global Navigation Satellite System and including the US Global Positioning System, GLONASS its Russian equivalent and the future European GALILEO and the Chinese BEIDOU (Big

Dipper) is playing more and more important role in high precision positioning missions in structure/construction health monitoring.

For achieving a particular purpose, a properly configured GNSS measurement system can meet most of the possible static and dynamic measurement needs in such applications for absolute positioning and relative displacement.

In other words the required precision and accuracy can be approached with architecture of the GNSS single/dual (L1 or L1/L2) frequency carrier phase, data sampling rate, communication between GNSS receivers and control data centre and the method of data processing.

GNSS for Structural Health Monitoring

GNSS is a very interesting tool for monitoring because it has a number of distinct advantages over terrestrial positioning technologies. GNSS is able to measure at high rates with low latency, operate in all weather conditions, has synchronized measurement, does not require line of site to ground marks/targets, can measure over long baselines, has low maintenance and a long service life and can provide timing for other sensors, such as accelerometers.

These unique characteristics make GNSS particularly interesting for monitoring large structures such as long bridges, dams, high rise buildings but also for seismic and land slide applications and for the provision of control for other instruments, such as robotic total stations, in unstable areas.

Each point to be measured must have an antenna, a receiver, ground mark, power, communications and, possibly, protection against lightning and vandalism or theft.

The reference stations receivers from where the baseline to the monitoring receivers will be processed must be installed in a stable place as all the results will refer to this. The minimum required is only one but to ensure an independent control on the solution and to have also an internal control on the relative stability of their location it is suggested to set-up at least two.

Leica Geosystems has developed dedicated GNSS receivers like the Leica GMX901 (see Figure 1) and the Leica GMX902 (see Figure 2) for monitoring applications complemented by GNSS antenna's that has the capacity to mitigate and reduce the multipath effects induced by the structure itself in many cases.

The Leica GNSS Monitoring Receivers



Figure 1 Single Frequency GMX901



Figure 2 Dual Frequency GMX902

The Leica GPS AT504 GG Choke Ring Antenna (see Figure 3) provides the state of art in GNSS signals tracking even in multi-path environment and radio jamming and the Leica AX1202 GG Geodetic antenna (see Figure 4) fits well any GNSS monitoring project until the location can be guaranteed free of multi-path effects. During the design phase of a GNSS monitoring project, the choice of the proper antenna will be one of the most important topics.

The Leica GNSS Antennas



Figure 3 AT504 GG Choke Ring Antenna



Figure 4 AX1202 GG Geodetic Antenna

In monitoring applications, accuracy is of paramount importance, so only ambiguity-fixed positions are of interest. A highly reliable ambiguity resolution strategy is needed to prevent wrong fixes, which will be detected immediately by the monitoring system as an apparent movement.

The processing kernel that has been developed for the bridge GNSS monitoring solution is based on that used in Leica Geosystems high-end RTK GNSS sensors and the LGO (Leica GeoOffice) post-processing software.

Real Time and Post-Processing modes

The kernel, which is integrated into the Leica GNSS Spider reference station and GNSS monitoring software, is able to process single and dual frequency data from GPS and/or GLONASS in real time and post processing. Three ambiguity resolution techniques has been implemented and successfully tested on many projects: Kinematic On the Fly (OTF), Initialisation on a Known Mark and the new Leica innovative Quasi-Static approach. The OTF technique allows full dynamics of the rover antenna suitable for use in formula one racing. The quasi-static approach uses assume lower dynamics such as would be experienced in most monitoring applications like the one we will have for the Yeong Jong Bridge in Korea.

The traditional approach to real time GNSS monitoring is to deploy RTK enabled receivers to the field, which receive corrections from a nearby reference station and self compute their positions. This distributed processing approach has some distinct disadvantages:

Two communications lines are required per point that is measured (one to receive the corrections and one to transmit the resulting coordinates,

- Only one baseline can be computed per point,
- Single frequency RTK is not supported,
- Post processing is not possible, and
- Archiving of the raw observations is not possible.

In the decentralized approach used by Leica GNSS Spider, only a single communication channel is required to send the raw observations to the monitoring server. Multiple baselines

may be computed for each point using different reference stations or processing parameters. Single frequency RTK is supported, as is post processing and archiving of both raw data and results. In the case of unreliable communications, it is also possible to log directly in the memory of the GNSS and then download the data periodically for post processing, rather than relying on having a permanent open communications channel. In that case the GNSS receivers used must have local storage capacity on flash card memory.

The Leica GNSS Spider software is dual-purpose software. It offers comprehensive GNSS reference station capabilities for the configuration and control of GNSS sensors, archiving of data and dissemination of correction data for single-base and network RTK positioning.

In addition to the reference station capabilities, GNSS Spider has advanced GNSS baseline processing capabilities for monitoring applications. The marriage of reference station and GNSS monitoring features produces a flexible and powerful application with sophisticated communications, processing, data management and security functionality.

GNSS Spider may be combined with Leica GNSS QC coordinate analysis software as well as with any third party monitoring and analyzing software for integration with other geotechnical sensors and to leverage the GNSS QC advanced limit checks, messaging and analysis features. The integration is easily made by streaming out the results in real time as well through TCP/IP ports, serial interface or Modem. All the results can be stored in text files as well for further analysis investigations.

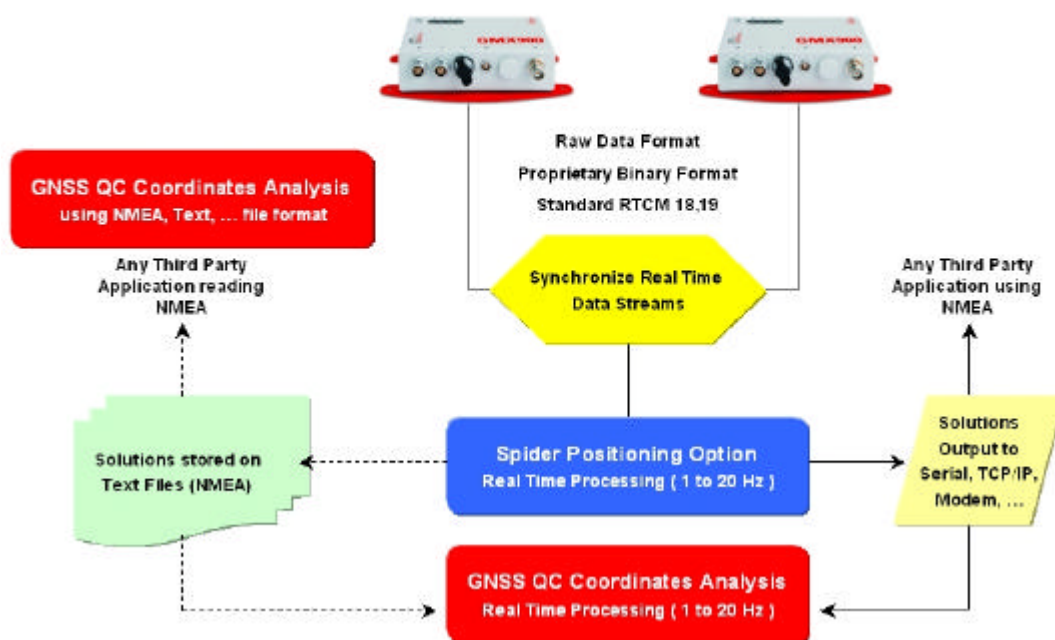
The baseline processing in Leica GNSS Spider is divided in two parts: real time processing and post processing. The Leica GNSS Spider also has the capacity to re-process complete observation files in RINEX format in those two modes. It's particularly interesting during the design phase whereby receivers can be placed temporarily to collect 24hour or 48 hour data and then processed at a later stage. The advantage of this is that performance of the system can be analysed prior to permanently fixing cabling for power and communications as well as estimating any errors associated with multipath.

Real Time Monitoring With GNSS Spider

The real time processing kernel is based on that used in the Leica GNSS RTK rover, but has been modified for monitoring applications. The Leica Smart Check technology, which is an evolution of the repeated search process, is used to continuously re-verify the ambiguity fix to ensure the highest reliability. With this improved kernel GNSS Spider is able to compute RTK-fixed positions from both single and dual frequency data at extremely high reliability..

Three ambiguity resolution techniques are available: Kinematic on the fly (also known as OTF or While Moving initialisation), Initialisation on Known Marker (IOKM) and Quasi-Static (QSI). The OTF ambiguity resolution allows for full receiver dynamics during the initialisation at the cost of reliability, especially for single frequency processing. The IOKM ambiguity resolution assumes strictly limited receiver dynamics (which is not practical for monitoring) but has much higher reliability. The QSI technique is combination of the previous two techniques – it allows for the antenna to be in motion during the initialisation but not to the same extent as OTF initialisation.

GNSS Processing Strategies Real Time from 1Hz up to 20Hz

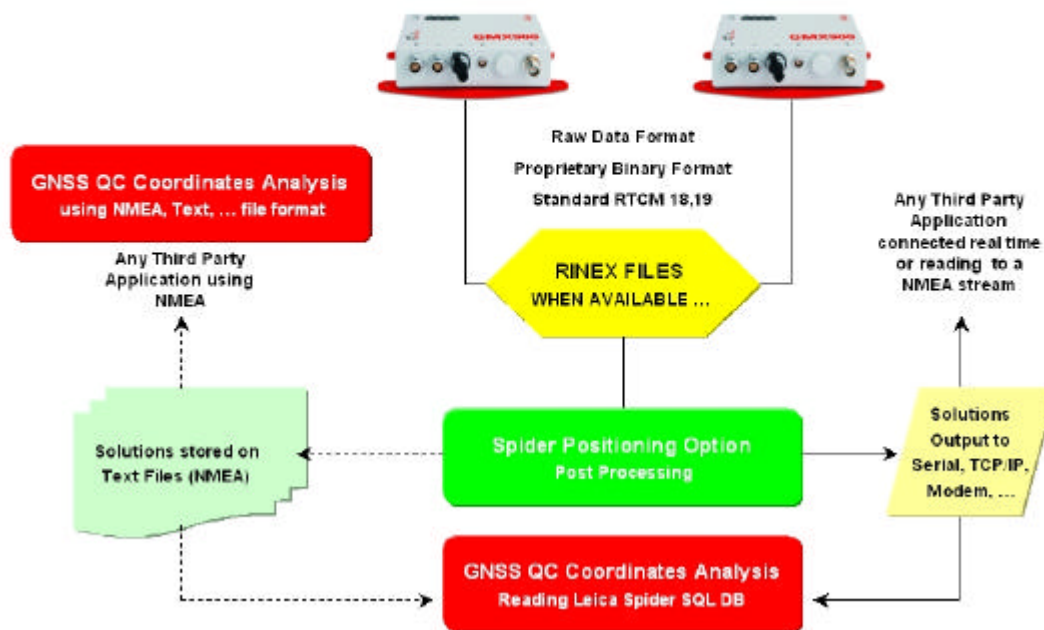


Post Processing Monitoring With GNSS Spider

The post-processing kernel used in GNSS Spider is based on that used in LGO. Like with the real time processing, a repeated search process is used to ensure highly reliable ambiguity resolution.

In addition, the initialisation on float marker is used to further improve the reliability. Post-processing intervals of between 1 minute and 24 hours are possible for dual frequency data and between 10 minutes and 24 hours for single frequency data.

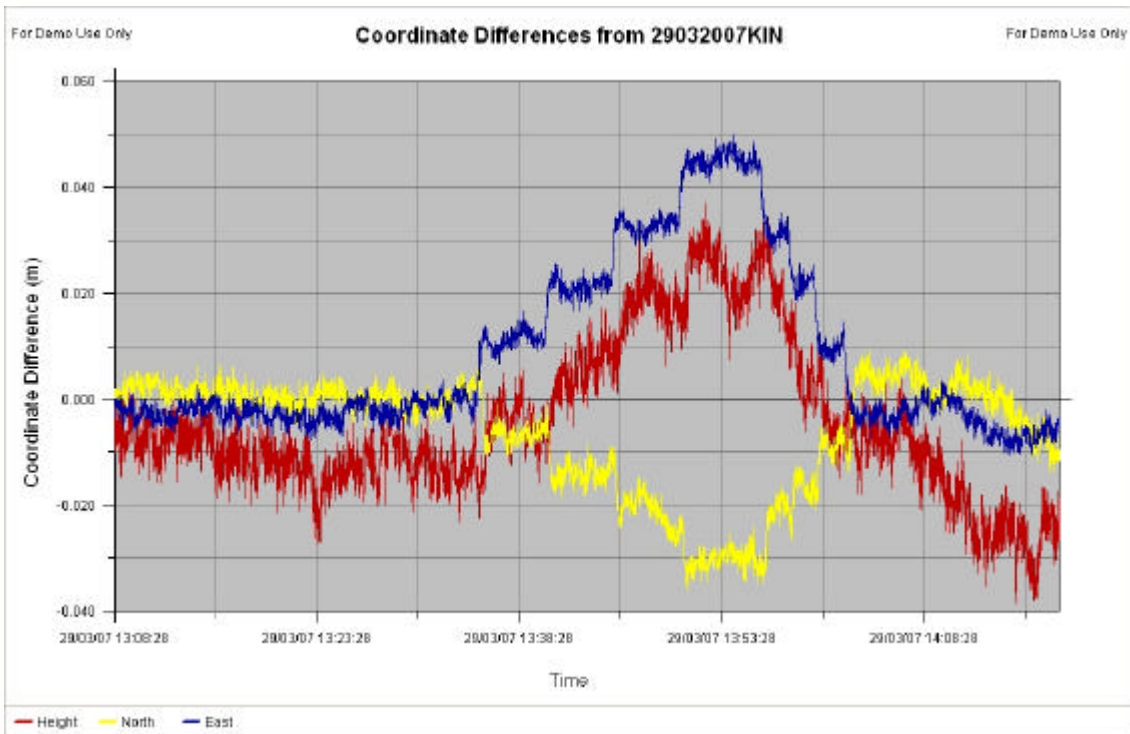
GNSS Processing Strategies Near RT and Post-Processing ...



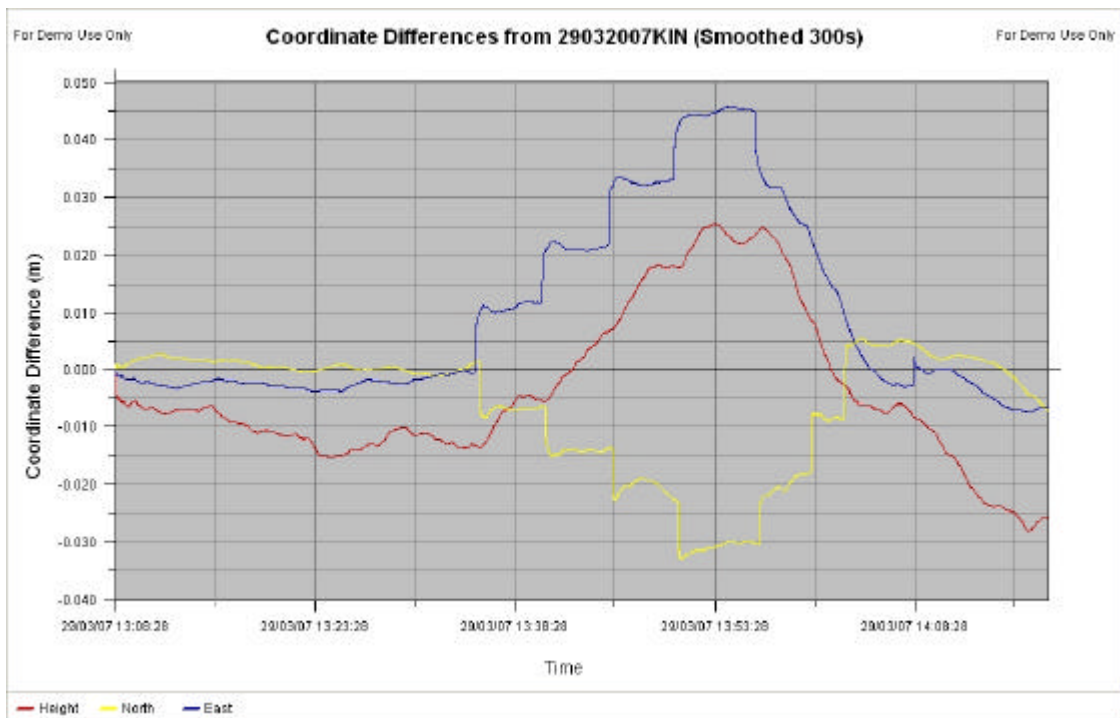
Reducing Inherent GNSS result noise by using Low Pass Band Filtering

Due to the nature of the different sources that affects the solution of GNSS measurements like the atmospheric delays, the orbital errors and the multi-path effects in some extend, the results are generally noisy and will not reflect at first look the full potential of the solution.

Therefore it is necessary to reduce the noise by using digital signal processing filtering techniques. Leica GNSS Spider has that capacity and various tests have demonstrated that up to 30% to 45% of the noise are effectively reduced.



Real Time results unfiltered and resulting from a maximum displacement of 4 cm.



Real Time results filtered and resulting from a maximum displacement of 4 cm.

Implementation of an Engineering Structure Monitoring solution

A typical Engineering Structure Monitoring Solution proposal is based on a dedicated monitoring design, which must address the following questions:

- How many monitoring station must be deployed on the infrastructure, where they should be located and which kind of support (mast, fixture) is allowed?
- Where will be the location of the GNSS Reference station(s). How many do we need? These stations play a very important role in the monitoring point determination and must be located on a very stable area...
- Do we need the results in real time or/and in post processing?
- What is the infrastructure project size? (3 km over 300 meters e.g.)
- Do we need to convert the results in a local datum? Which local datum? Who will deliver the parameters?
- How can we power up safely the GNSS receivers? Lightning protection? Do we need to interface the GNSS receivers with other sensors like tilt-meters, meteorological stations etc.?
- Where we will the control centre hosting Leica SPIDER Server be located? To which application(s) must we interface the output results? Do we have to provide a PC computer with peripheral(s)?
- A technical map must be provided with the location of the reference station(s), the monitoring stations and the control centre.
- What environmental conditions surround the GPS monitoring stations?
- What is the required accuracy for X-Y coordinates? (Horizontal displacements)
- What is the required accuracy for Z-coordinate? (Vertical displacements)
- Required measurement frequency? (20Hz, 5Hz, 1Hz, slow motion, static)
- Expected movement's entity? (mm/hour, cm/day, dm/year, etc.)
- Planned/preferred communication link between measuring stations and Control Centre?
- Object extension: which is the maximum distance between two monitoring stations?
- Sky visibility. Presence of obstacle (structures, cables.) that could restrict the satellites visibility?
- Is there a budget already allocated for this monitoring project?
- Planned time-schedule: Monitoring system installation? Measurement start?
- How many GNSS sensors and their GNSS antenna, including various accessories like cables, power supplies, uninterruptible powering system, lightning protection, mast and adapters must be provided?
- Does the receiver have to log the raw data or/and just to stream? How many ports? Does it have to synchronize other monitoring equipment on GPS time (PPS)?
- What will be the solution for the communication interfaces and lines?
- Which modules of Leica GNSS Spider software must be delivered?
- What kind of analysis software will be used and which interface should be delivered?

Type of services to provide :

- Feasibility study, support for the monitoring project design, location of the monitoring stations, processing scheme, simulations, multi-path analysis...
- Comprehensive and clear quotation including delivery terms...
- Installation, tests, training, support and commissioning...
- Maintenance contract including upgrade proposals for both hardware and software...

Conclusion

The ability to monitor real-time data from a remote location is a critical issue due to the divergence often found between the location of structures and the location of the people charged with monitoring those structures.

Leica Geosystems can provide GNSS monitoring systems that gather the data and feed it to a remote location via the Internet to give you 24/7 monitoring capability from any location.

Whether the movement occurs over a period of seconds, minutes, hours, days, weeks or months, the system is able to track the movement. Parameters can be set such that any movement outside a designated range can automatically notify the responsible people. This timely information gives the operators time to take an appropriate response and avoid any critical failures.

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